ESTIMATION OF PLASMA PARAMETERS IN A GAS-DISCHARGE TUBE USING THE TERMINAL CHARACTERISTICS AND A TRANSIENT COMPUTER MODEL

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ABSTRACT

A transient computer model[1] is used to estimate plasma parameters in a high-current demountable Cs-Ba tacitron. The model couples the external circuit to the plasma discharge, and calculates electron energy, plasma density, sheath potentials, cesium coverage on the emitter surface, forward voltage drop, and discharge current as functions of time. Fitting the model I-V curve to the measured I-V characteristic of an experimental device provides an estimate for various internal physical parameters using only the terminal characteristics of the device and the reservoir and electrode temperatures.

The high-current demountable Cs-Ba tacitron was designed and fabricated at the Russian Scientific Center, Kurchatov Institute, and tested by the University of New Mexico's Pulsed Power and Plasma Sciences Laboratory[2] as part of a program to develop radiation-hard switching elements for use in space nuclear power applications. In addition to demonstrating high-current operation, testing of this tacitron was intended to provide scaling information for future efforts. Estimates of internal physical parameters, based on the transient computer model, are used to provide greater insight on device scaling.

INTRODUCTION

A series of papers were presented at the Tenth IEEE International Pulsed Power Conference [2-4] that described the performance of two Cs-Ba tacitrons designed and fabricated at the Russian Scientific Center, Kurchatov Institute, and tested by the University of New Mexico. The two tacitrons, one a sealed

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14. ABSTRACT
A transient computer model[ll is used to estimate plasma parameters in a high-current remountable Cs-Ba tacitron. The model couples the external circuit to the plasma discharge, and calculates electron energy, plasma density, sheath potentials, cesium coverage on the emitter surface, forward voltage drop, and discharge current as functions of time. Fitting the model I-V curve to the measured I-V characteristic of an experimental device provides an estimate for various internal physical parameters using only the terminal characteristics of the device and the reservoir and electrode temperatures. The high-current remountable Cs-Ba tacitron was designed and fabricated at the Russian Scientific Center, Kurchatov Institute, and tested by the University of New Mexicos Pulsed Power and Plasma Sciences Laboratory121 as part of a program to develop radiation-hard switching elements for use in space nuclear power applications. In addition to demonstrating high-current operation, testing of this tacitron was intended to provide scaling information for future efforts. Estimates of internal physical parameters, based on the transient computer model, are used to provide greater insight on device scaling.

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device, the other a demountable high current device, are triode gas-discharge tubes, similar in construction to thyratrons. The primary difference between a tacitron and a thyratron is that the tacitron is designed to be completely grid-controlled, whereas a thyratron has grid control only over ignition. The high current device was designed to modulate average currents in the range of 100 to 200 A, with the intent of demonstrating proof-of-principle power conditioning capability for a 6 kWe direct energy conversion space power source.

Data gathered from the high current tacitron included I-V characteristics obtained while varying parameters such as emitter temperature and gas pressure. To come to a better understanding of the device, and thereby improve device performance, an understanding of the plasma parameters within the device was necessary. This paper describes the application of a transient computer model for low-pressure Cs-Ba discharges [1] in estimating plasma parameters within the high current tacitron by using terminal characteristics of the device. The model can calculate the electron energy, plasma density, density of ground and excited states of Cs, sheath potentials, Cs coverage on electrode surfaces, and forward voltage drop.

DESCRIPTION OF THE COMPUTER MODEL

In the original work by Luke and El-Genk [1] the governing equations for the Cs-Ba diode transient model were simplified by making a variety of assumptions. The plasma was assumed to be made up of electrons, ionized Cs atoms in the ground state, and neutral Cs atoms in the ground and first four excited states. Because Ba has a much lower base pressure than Cs in these devices, Ba is assumed not to participate in the plasma. The plasma is assumed to be neutral, with electric fields small and all potential drops occurring in the Langmuir sheaths near the electrodes. The relatively low current density allows magnetic field effects to be neglected, and since the discharge gap is modeled as an open volume, particles are free to enter and leave the gap during the discharge, including adsorption and desorption from the electrode surfaces.

Because the mean free path is greater than the width of the discharge gap, beam electrons do not directly interact with the plasma and the elastic collision cross sections are averaged over the Maxwellian electron energy distribution function of thermal electrons. The plasma is also assumed to be homogeneous throughout the discharge volume.

DESCRIPTION OF THE TACITRON

Figure 1 shows a schematic of the tacitron. The emitter heater consists of a wound tungsten filament placed within a molybdenum emitter cup. A molybdenum spacer is used between the upper lip of the emitter cup and the boron-alumina nitride ceramic insulator that isolates the emitter from the grid. The grid is a honey-comb design in 6 quadrants, constructed of 1-mm wide tantalum ribbon with a mean cell diameter of approximately 1 mm. The quadrants are separated by 1 mm thick struts running radially outward from a 1.6-cm diameter hub. The collector electrode is isolated from both the base flange and the grid electrode by boron-alumina nitride ceramic insulator. Emitter and collector planar surface areas are 28 cm^2 and 27 cm^2, respectively. The grid has the same planar area as the emitter, with a transparency of 65%. The grid is located approximately in the center of the emitter-collector gap, with grid-collector and grid-emitter electrode separations of approximately 1.5 mm. External reservoirs allow cesium and barium pressures to be controlled independently of emitter temperature. The Ba reservoir consists of a molybdenum cup mounted on an upright linear feedthrough below the base flange, while the Cs reservoir is placed outside the vacuum chamber. During device operation, the base flange is maintained at a temperature approximately 30 - 80° C higher than the Ba reservoir to prevent Ba and Cs condensation within the flange. The temperature gradient between the emitter and the base flange insures that the internal surfaces of the tacitron are hot enough to remain free from excessive Cs or Ba condensation. The Cs orifice plug in the base flange Cs delivery line serves to minimize the diffusion of Ba into the Cs system.

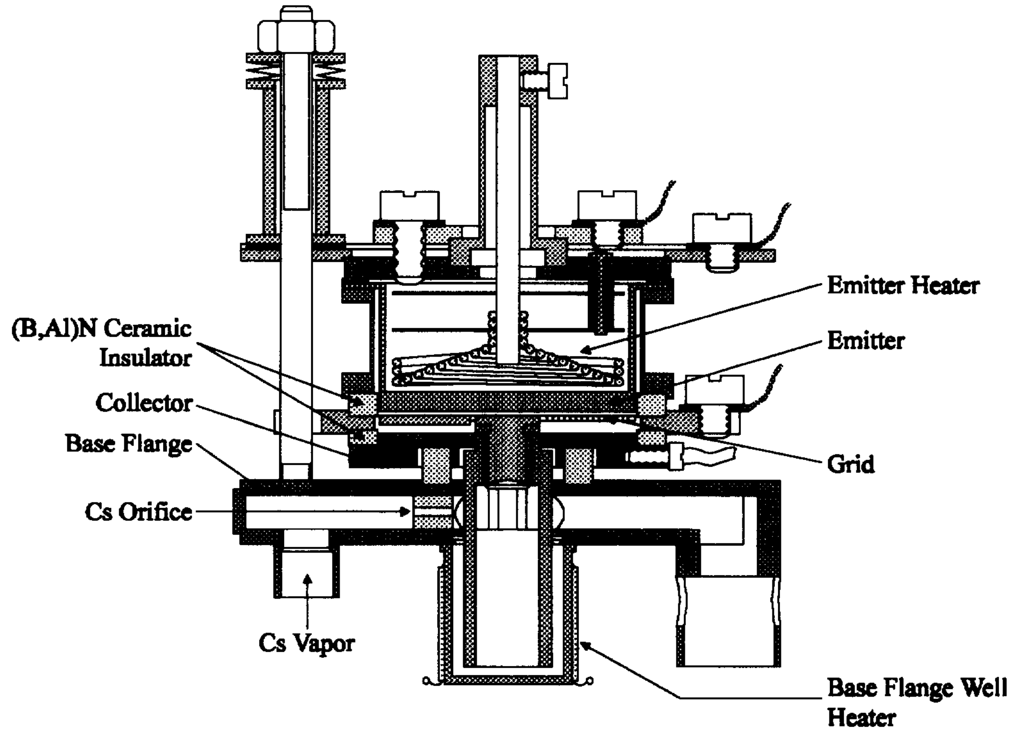

Figure. 1: Schematic illustration of the high-current Cs-Ba tacitron.

PRELIMINARY RESULTS

Figure 2 presents a set of experimental I-V curves taken at constant emitter temperature and barium pressure, but differing cesium pressures[5]. Model results for these device conditions are displayed in Figure 3. Note the general correlation between the model and the experimental data – as cesium pressure increases, the forward voltage drop (V_{CE}) decreases below the knee, and the peak current increases in the Schottky emission region above the knee. In terms of the general trends, the model behavior is good, and indicates that the most significant aspects of the underlying physics has been modeled correctly.

However, it is apparent that the model does not closely predict the actual forward voltage drop of the device. This is probably not a fundamental limitation of the model, as the fit between the original model implementation and a small planar diode was quite good[1]. The most likely cause for the discrepancy between this model implementation and experimental data is the absence of a grid electrode in the model. The grid surface area for this device is greater than the combined surface areas of the collector and emitter electrodes – providing a large surface for adsorption of Cs atoms and energy loss from the plasma. Consider that at a Cs-reservoir temperature of 130° C, the total number of Cs atoms in the discharge volume is about 10^{15}, while the number of Cs atoms in a full monolayer on all electrode surfaces is greater than 10^{16}. Of course, at operating temperature, the Cs coverage on the collector is generally no more than a few percent prior to discharge, and rapidly drops during discharge, while the coverage on the emitter is about an order of magnitude less than that on the collector[6]. Electrode surfaces do, however, provide a significant source of neutral Cs atoms during the discharge.

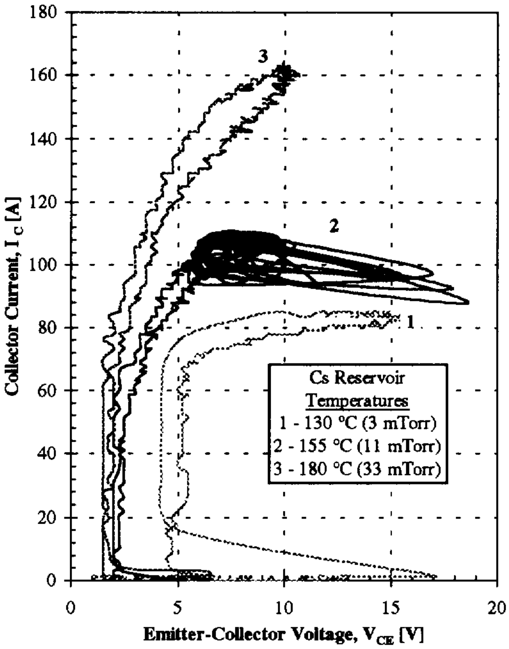

Figure 2: I-V curves taken at constant emitter temperature (T_E = 1050° C) and barium pressure (P_{ba} = 2.9 mTorr), but differing cesium pressures.

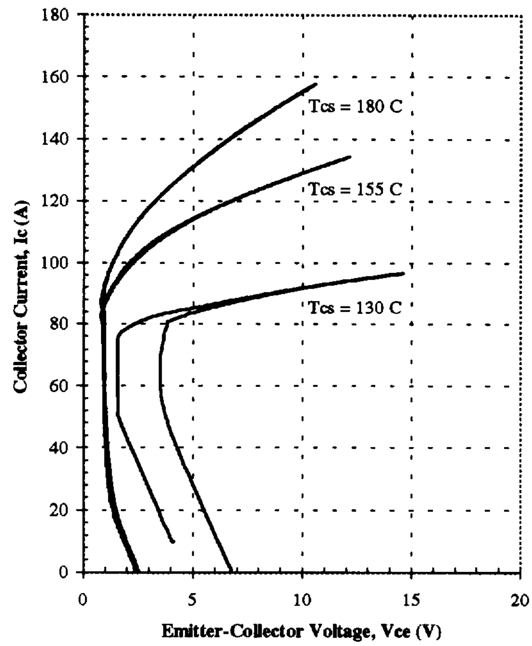

Figure 3: Model I-V curves at constant emitter temperature (T_E = 1050° C) and barium pressure (P_{ba} = 2.9 mTorr), but differing cesium pressures.

Figure 4 illustrates the model estimates of plasma density for the three cases depicted in Fig. 3. Not surprisingly, the higher the Cs pressure, the higher the plasma density during discharge. Figure 5 illustrates the model estimate of electron temperature for each case. Again, the model output is consistent with the expectation that electron temperature will be higher in those cases for which the forward voltage drop is higher. Model cesium pressure during the discharge, relative to the starting pressure, is depicted in Figure 6, and is consistent with the modeled Cs coverage on the collector.

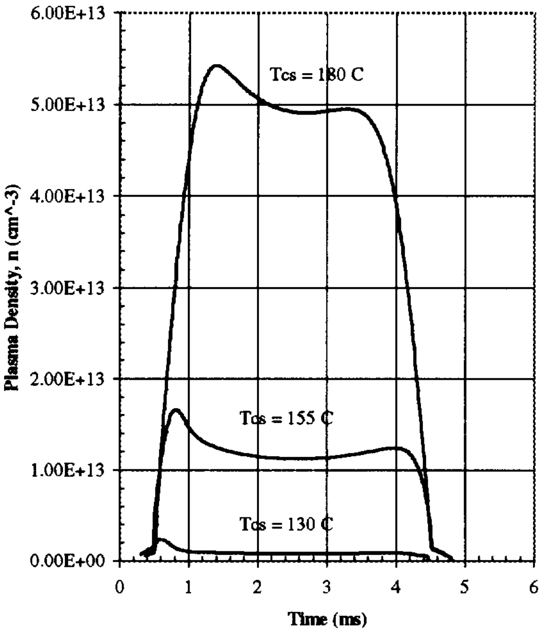

Figure 4: Plasma density for the three cases of Fig. 3.

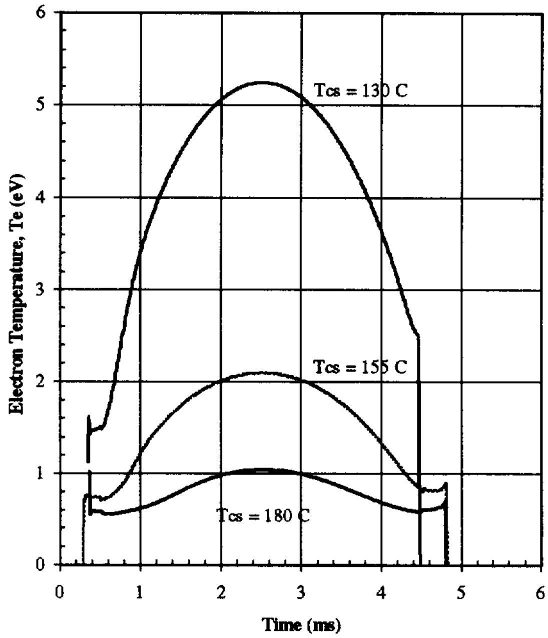

Figure 5: Electron temperature for the three cases of Fig. 3.

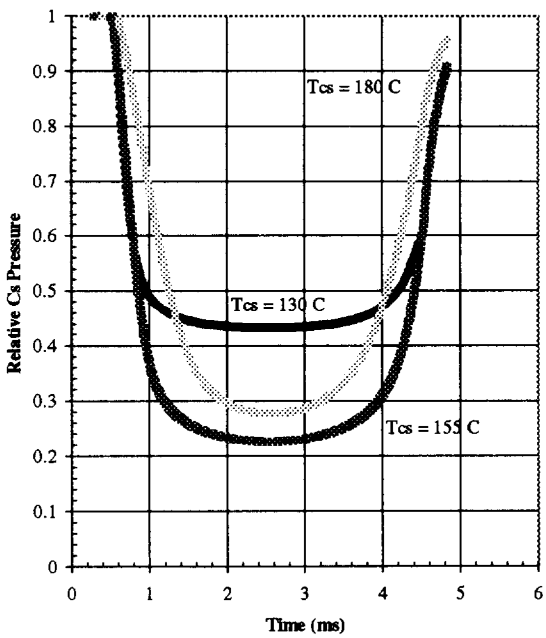

Figure 6: Relative Cs pressure in the discharge volume for the three cases of Fig. 3.

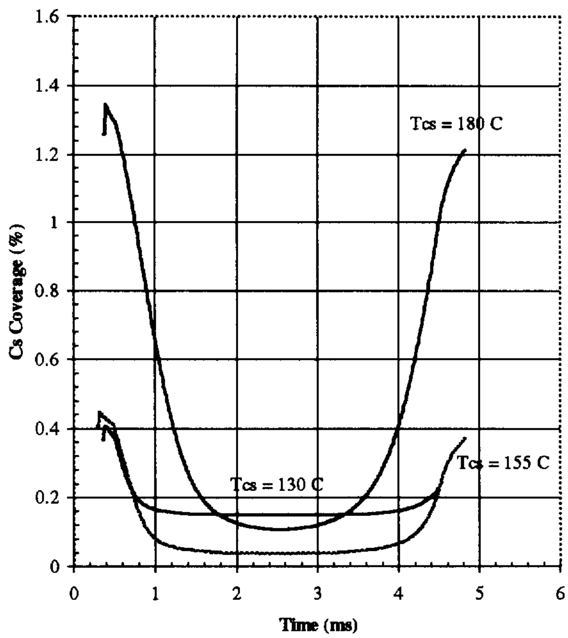

Figure 7: Cesium coverage on the collector for the three cases of Fig. 3.

DISCUSSION

The computer model[1] reflects the trends in the measured I-V curves, but thusfar fails to accurately predict device performance. This is probably due primarily to the absence of a grid in the model, since it is known that the grid contributes to higher voltage drops in triodes versus diodes, and the computer model does accurately predict the performance of diode devices[1].

Future work will incorporate the grid into the model, in order to accurately predict I-V performance of the device. In addition, an attempt will be made to simulate grid-controlled current modulation, although the mechanism[7,8] thought to be primarily responsible for current quenching in thick-grid tacitrons is not particularly amenable to simulation.

REFERENCES

[1] J. R. Luke and M. S. El-Genk, "Low-Pressure Cs-Ba Discharge. I. Model Development," *Journal of Applied Physics*, Vol. 78, No. 6, 15 September 1995.

[2] G. B. Masten, I. Djachiachvili, D. Brent Morris, and J. M. Gahl, "Operating Characteristics of a High-Current Demountable Cs-Ba Tacitron," *10th IEEE Pulsed Power Conference*, Albuquerque, NM, July 10-13, 1995.

[3] G. B. Masten, D. Hidinger, I. N. Djachiachvili, G. Sharp, and J. M. Gahl, "Operating Characteristics of a Sealed-Prototype Cs-Ba Tacitron," *10th IEEE Pulsed Power Conference*, Albuquerque, NM, July 10-13, 1995.

[4] G. B. Masten, I. N. Djachiachvili, D. B. Morris, and J. M. Gahl, "Preliminary Performance Results of a High-Current Cs-Ba Tacitron in a Simple Inverter," *10th IEEE Pulsed Power Conference*, Albuquerque, NM, July 10-13, 1995.

[5] D. B. Morris, "Preliminary Performance Characterization of a High-Current Cs-Ba Tacitron," MS Thesis, Department of Chemical and Nuclear Engineering, University of New Mexico, 1996.

[6] J. R. Luke and M. S. El-Genk, "Low-Pressure Cs-Ba Discharge. II. Probe Measurements," *Journal of Applied Physics*, Vol. 78, No. 6, 15 September 1995.

[7] M. S. El-Genk, C. Murray, and Glen McDuff of ISNPS, and V. Kaibyshev, A. Borovskikh, Y. Djashiashvili, and Y. Taldonov of the Kurchatov Institute of Atomic Energy, "Peculiarities of the Discharge Breakdown of the Cs-Ba Tacitron," *Proceedings of the 2nd Thermionic Specialist Conference of the USSR*, Sukhumi, USSR, Oct. 28 - Nov. 2, 1991.

[8] C. Murray, B. Wernsman, and M. S. El-Genk of ISNPS, and V. Kaibyshev of the Kurchatov Institute of Atomic Energy, "Ignition and Extinguishing Characteristics of Cs-Ba Tacitron," *Journal of Applied Physics*, Vol. 72, No. 10, 15 Nov. 1992.